Laser Sounder for Global Measurement the CO2 Concentrations in the Troposphere from Space

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Abstract: We report progress in assessing the feasibility of a new satellite-based laser-sounding instrument to measure CO2 concentrations in the lower troposphere from space.

1. Introduction

CO_2 measurements from ice cores show that atmospheric CO_2 concentrations are higher now than they have been in the past 400,000 years. It is becoming increasingly important to understand the nature and processes of the CO2 sinks, on a global scale, in order to make predictions of future atmospheric composition. Accurate measurements of tropospheric CO2 abundance with global-coverage, 300 km spatial and monthly temporal resolution are needed to quantify processes that regulate CO2 storage by the land and oceans [1]. The NASA Orbiting Carbon Observatory (OCO) is the first space mission focused on atmospheric CO_2 for measuring total column CO_2 and O_2 by detecting the spectral absorption in reflected sunlight. The OCO mission is a key first step, and will yield important new information about atmospheric CO_2 distributions. However they are unavoidable limitations imposed by its measurement approach. These include best accuracy only during daytime at moderate to high sun angles, interference by cloud and aerosol scattering, and limited signal from CO_2 variability in the lower tropospheric CO_2 column. The recent NRC Decadal Survey for Earth Science [2] has recommended addressing these un-met needs in a laser-based CO2 measuring mission called ASCENDS.

We have been in developing a laser technique for the remote measurement of the tropospheric CO2 concentrations from orbit [3-6]. Our initial goal is to demonstrate a lidar technique and instrument technology that will permit measurements of the CO2 column abundance in the lower troposphere from aircraft at the few ppm level. Our final goal is to develop a space instrument and mission approach for active CO2 measurements. This would allow continuous measurements of CO2 mixing ratio from orbit, both day and night, over land and ocean surfaces, and under realistic atmospheric scattering conditions.

2. Approach

Previous and ongoing efforts to develop laser instruments for measuring atmospheric CO2 have used the 4.88 μm [7] and 2 μm [8-11] wavelengths. Our approach is to use the 1570nm band (Figure 1) and a dual channel laser absorption spectrometer (ie DIAL lidar used an altimeter mode), which continuously measures at nadir from a near polar circular orbit (Figure 2). It uses several tunable fiber laser transmitters allowing simultaneous measurement of the absorption from a CO2 absorption line in the 1570 nm band [12] and O2 extinction in the oxygen A-band, and aerosol backscatter in the same measurement path. It directs the narrow co-aligned laser beams from the instrument's lasers toward nadir, and measures the energy of the laser echoes reflected from land and water surfaces. During the measurement the lasers are tuned on- and off- a selected CO2 line near 1572 nm and a selected O2 line near 765 nm in the Oxygen A band at kHz rates.

The lasers are a MOPA architecture using tunable diode seed lasers and fiber amplifiers, and have spectral widths much narrower than the gas absorption lines. The receiver uses a 1-m diameter telescope and photon counting detectors [13], and measures the background light and energies of the laser echoes from the surface along with scattering from any clouds and aerosols in the path. The gas extinction and column densities for the CO2 and O2 gases are estimated from the ratio of the on and off line signals via the differential optical absorption technique.

Pulsed laser signals and time gating are used to isolate the laser echo signals from the surface, and to exclude photons scattered from clouds and atmospheric aerosols.

The 1570 nm CO2 band [13] is well suited for this measurement. It is largely free from interference, has absorption lines with the needed temperature insensitivity and strengths [14], and is within the spectral range of high power lasers and sensitive photon counting detectors. Our technique uses the on-line wavelengths tuned to the sides of the gas absorption line. This exploits the atmospheric pressure broadening of the gas lines to weight the measurement sensitivity to the atmospheric column below 5 km. This maximizes sensitivity to CO2 changes in the boundary layer where variations caused by surface sources and sinks are largest. Simultaneous measurements of O2 column are planned using a selected region in the oxygen A band. Laser altimetry and atmospheric backscatter profiles are also measured simultaneously, which permits determining the surface height and measurements made to thick cloud tops and through aerosol layers.

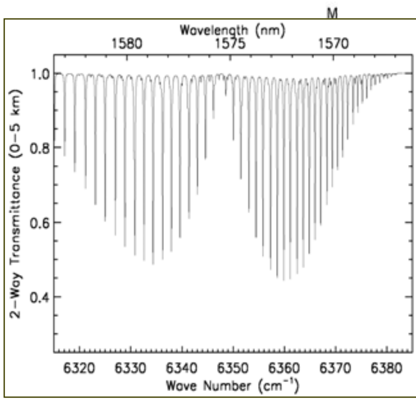

Figure 1- Co2 Absorption from space (HITRAN) in 1570 nm band

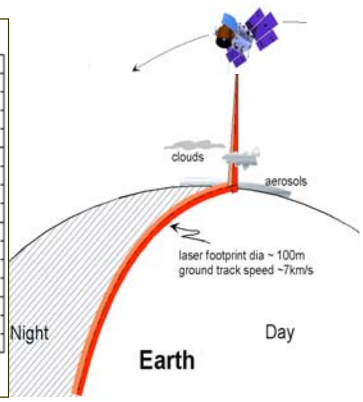

Figure 2 - Orbital Measurement concept

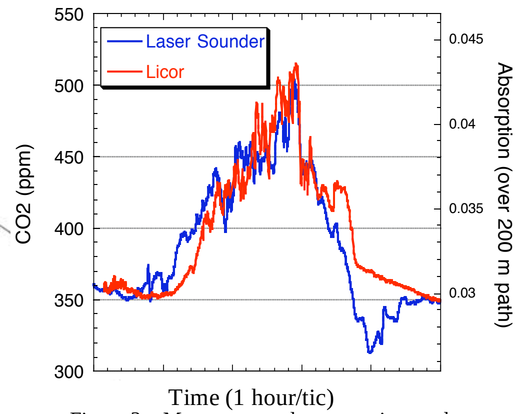

Figure 3 – Measurement demonstration made from lab over 206 m horizontal path.

The laser sounder approach has some fundamental advantages over measurements with passive sensors using reflected sunlight. It measures gas absorption in a common nadir/zenith path and the narrow laser divergence produces small laser footprints. The laser sources allow measurements in sunlight and darkness allowing global coverage. It can measure continuously over the ocean, to cloud tops and through broken clouds. The lasers are pulsed and potential measurement errors from scattering from clouds and aerosols are greatly reduced by using time gating in the receiver. Nonetheless, the optical absorption change due to a few ppm change in CO2 is quite small, <1%, which makes achieving measurement sensitivity and stabilities challenging. Signal-to-noise ratios and measurement stabilities of > 700:1 are needed to allow CO2 mixing ratio estimates at the few ppm level.

We have calculated several characteristics of the technique, and have demonstrated key aspects of the laser, detector and receiver approaches in the laboratory. We have also measured O2 in an absorption cell, and CO2 over 206 and 400m long open horizontal paths [6] using a breadboard version of the sensor (Figure 3). We will describe these measurements and show details on our approach in the presentation.

3. References

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